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A COMPUTER PROGRAM FOR ESTIMATION OF PARAMETERS OF THE WEIBULL INTENSITY FUNCTION AND FOR THE CRAMER-VON MISES GOODNESS OF FIT TEST

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U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
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This report describes the structure and use of a digital computer program written in Standard FORTRAN, which can be used to obtain the maximum likelihood estimates of the parameters of the Weibull intensity function. The program also performs the Cramer-Von Mises goodness of fit test.

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A COMPUTER PROGRAM FOR ESTIMATION OF PARAMETERS OF THE WEIBULL INTENSITY FUNCTION AND FOR THE CRAMER-VON MISES GOODNESS OF FIT TEST

1. INTRODUCTION

The Weibull intensity function

$$U(X) = \lambda\beta X^{\beta-1} \tag{1.1}$$

$\lambda>0$, $\beta>0$, $X>0$, is frequently used as a model for the determination of reliability growth and wear-out characteristics for a wide variety of complex, repairable systems. The failure rates of military equipment such as vehicles, aircraft, guided missiles, electronic computer systems, and ammunition are being evaluated using this model.

Formulas have been developed by the Army Materiel Systems Analysis Activity (AMSAA) for the maximum likelihood estimation of the unknown parameters λ and β, based upon sample data. These estimation formulas for the Weibull process, found in Crow (1975), can be stated as

$$\hat{\beta} = \frac{\sum_{i=1}^{K} N_i}{\hat{\lambda} \sum_{i=1}^{K} (T_{i2}^{\hat{\beta}} \ln T_{i2} - T_{i1}^{\hat{\beta}} \ln T_{i1}) - \sum_{i=1}^{K} \sum_{j=1}^{N_i} \ln X_{ij}} \tag{1.2}$$

$$\hat{\lambda} = \frac{\sum_{i=1}^{K} N_i}{\sum_{i=1}^{\hat{K}} (T_{i2}^{\hat{\beta}} - T_{i1}^{\hat{\beta}})} \tag{1.3}$$

where:

- K is the number of systems under study;
- N_i is the total number of failures (or occurrences of an event under study, such as unscheduled maintenance actions; etc.) for the i^{th} system;
- T_{i1} is the starting time of the period of continuous observation of the i^{th} system;
- T_{i2} is the ending time of the period of continuous observation of the i^{th} system;
- X_{ij} is the j^{th} time of occurrence of the failure (or event), for the i^{th} system;

ln is the natural logarithm, and $0 \cdot \ln(0)$ is defined to be 0.

To expedite the computation of these estimates, AMSAA developed a FORTRAN computer program to calculate $\hat{\beta}$ and $\hat{\lambda}$. That program, which was documented in Belbot (1974), was successfully employed by the U S Army Materiel Development and Readiness Command (DARCOM), various subordinate commands and several project managers' offices, as well as by AMSAA. After the parameters were determined by that program, a goodness of fit test was frequently used to test statistically the hypothesis that the failure times of the systems being analyzed followed a nonhomogeneous Poisson process with Weibull intensity function (see Crow [1975]). The modified Cramér-Von Mises goodness of fit statistic was computed, either by hand or by a separate computer program.

Obviously, the consolidation of an automated goodness of fit test with the computer routine which estimates the parameters $\hat{\beta}$ and $\hat{\lambda}$, would increase efficiency and accuracy. Either the manual calculations or the use of a separate program would be eliminated. To accomplish properly this consolidation, the estimation procedure was subordinated to a new main program which also controls the input of data and the execution of the goodness of fit test. Because of the radical nature of this redesign, it was appropriate to incorporate other new features at the same time. Principal among these new features are a simplified input procedure and dynamic data storage allocation. The resulting computer program is easier to use and provides more information that its antecedent program. This note will explain the structure and the use of this new program.

2. COMPUTING PROCEDURE

2.1 Estimation of Parameters

Since the formulas (1.2) and (1.3) do not, in general, yield $\hat{\beta}$ and $\hat{\lambda}$ in closed form, an iterative technique is required. Formula (1.2) may be recast as

$$\frac{\sum_{i=1}^{K}\sum_{j=1}^{N_i} \ln X_{ij}}{\sum_{i=1}^{K} N_i} - \frac{\sum_{i=1}^{K}\left(T_{i2}^{\hat{\beta}} \ln T_{i2} - T_{i1}^{\hat{\beta}} \ln (T_{i1})\right)}{\sum_{i=1}^{K}\left(T_{i2}^{\hat{\beta}} - T_{i1}^{\hat{\beta}}\right)} - \frac{1}{\hat{\beta}} = 0 \tag{2.1}$$

by replacing $\hat{\lambda}$ by its equivalent expression from equation (1.3), and by execution of a few simple algebraic operations. Equation (2.1) now consists of a constant with regard to $\hat{\beta}$, minus a function of $\hat{\beta}$, yielding 0, or simply

$$A - D(\hat{\beta}) = 0 \tag{2.2}$$

The correct value of $\hat{\beta}$ will satisfy equation (2.2) and can be used to calculate the corresponding value of $\hat{\lambda}$.

The solution for $\hat{\beta}$ is iteratively determined in the following way. For an initial estimate $\hat{\beta}'$ which is assumed to be larger than the true $\hat{\beta}$, the expression $A-D(\hat{\beta}')$ is evaluated. For all values of $\hat{\beta}'$ larger than the true $\hat{\beta}$, the subtraction yields a negative result. After each negative result, $\hat{\beta}'$ is reduced by the initial step size of 1, and $A-D(\hat{\beta}')$ is again evaluated.

When a positive number results from the subtraction, indicating that $\hat{\beta}'$ is too small, the step size is decreased to 0.10 of the present step size, the previous value of $\hat{\beta}'$ which gave a negative result for $A-D(\hat{\beta}')$, is adjusted by the new step size and the evaluation process begins again.

The iteration procedure continues, adjusting $\hat{\beta}'$ by the new step sizes, until the left side of equation (2.2) is within a specified tolerance ε of 0. $\hat{\lambda}$ is then calculated based on $\hat{\beta}$, using factors already computed in finding $\hat{\beta}$. This procedure is summarized by the state diagram (Figure 2.1).

2.2 Goodness of Fit Test

The Cramer-Von Mises Goodness of Fit Test is appropriate whenever the starting time of each system is equal to 0. To perform this test, the program first transforms the failure times. For time truncated testing, the failure times for each system are divided by the ending time of the test period for that system. In failure truncated testing, for every system, all the failure times except the last, are divided by the last failure time. The last failure time is thereafter excluded from the calculations and the number of transformed failures is one less than the original number of failures for each such system. All the transformed failure times are then sorted into increasing order.

Next, the unbiased estimate $\bar{\beta}$ of the estimated shape parameter $\hat{\beta}$, is calculated using the relation:

$$\bar{\beta} = \frac{M-1}{N} \hat{\beta} \qquad (2.3)$$

where:

M is the number of transformed failure times;
and N is the number of original failure times.

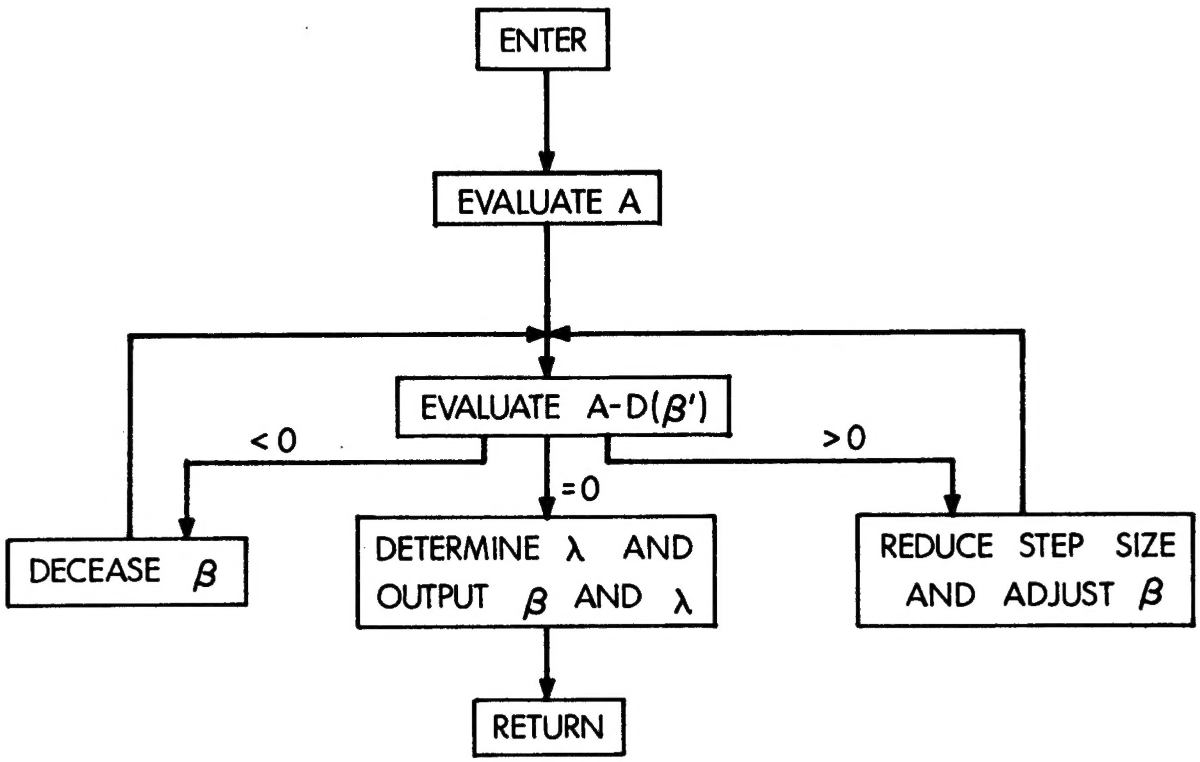

Figure 2.1 State Diagram

Finally, the Cramer-Von Mises statistic C_M^2 is computed by the formula:

$$C_M^2 = \frac{1}{12M} + \sum_{i=1}^{M} (\bar{Z}_i^{\beta} - \frac{2i-1}{2M})^2 \qquad (2.4)$$

where the Z_i are the transformed failure times. An explanation of this test and a table of critical values of C_M^2 may be found in Crow (1975).

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3. DESCRIPTION OF PROGRAM

3.1 Major Features

The program, which is listed in Appendix A, has some important features. First, the program is written in American National Standards Institute (ANSI) FORTRAN X3.9-1966, and should therefore execute on any computer having a compiler for this language. Secondly, the amount of storage required to use this program should not cause difficulties since all data arrays are dynamically allocated under control of the main program (see Chung-Phillips, et al., [1975]).

Finally, and perhaps most importantly for the user, this program uses free-field input, that is, no specific format is required for the input data. The time and the effort regularly expended in preparing data for input, are greatly reduced because of this feature. Moreover, the misalignment of data fields to formats, a frequent source of errors in using many computer programs, is eliminated entirely. While no input scheme can be regarded as foolproof, free-field input is much more flexible than fixed-field format specifications.

3.2 Overall Characteristics

All calculations in the program are made in double precision mode. Experience has shown that the use of single precision variables for these calculations often results in significant discrepancies in the estimates of the parameters due to errors accumulated during the iterative process.

The modular structure of the program (see Figure 3.1) reflects organization by functional purpose. The input of data, certain intermediate calculations, the estimation of parameters, and the goodness of fit test are each performed by an independent module. Major subprograms print their results as the values become available. Subroutines which detect errors, print diagnostic messages naming the detecting routine and briefly stating the difficulty, and then attempt to continue processing when possible. Independence of the subroutines is maintained by restricting communication between individual subprograms to the passage of formal parameters in argument lists. No COMMON statements are used.

3.3 Specific Details of Routines

In addition to controlling the major modules, the main program also allocates storage for data arrays, as stated in Section 3.1. The allocation is based upon the maximum number of failures, NFAIL, and the maximum number of systems, NSYS. The master data array, BLOCK, has a length of NTOTAL, equal to the value of NFAIL plus six times the value of NSYS. To redimension the entire program, one merely adjusts the values of NFAIL, NSYS and NTOTAL in the DATA statements at the beginning of the main routine and changes the size of the array BLOCK, also found at the beginning of the main program, to equal the new value of NTOTAL.

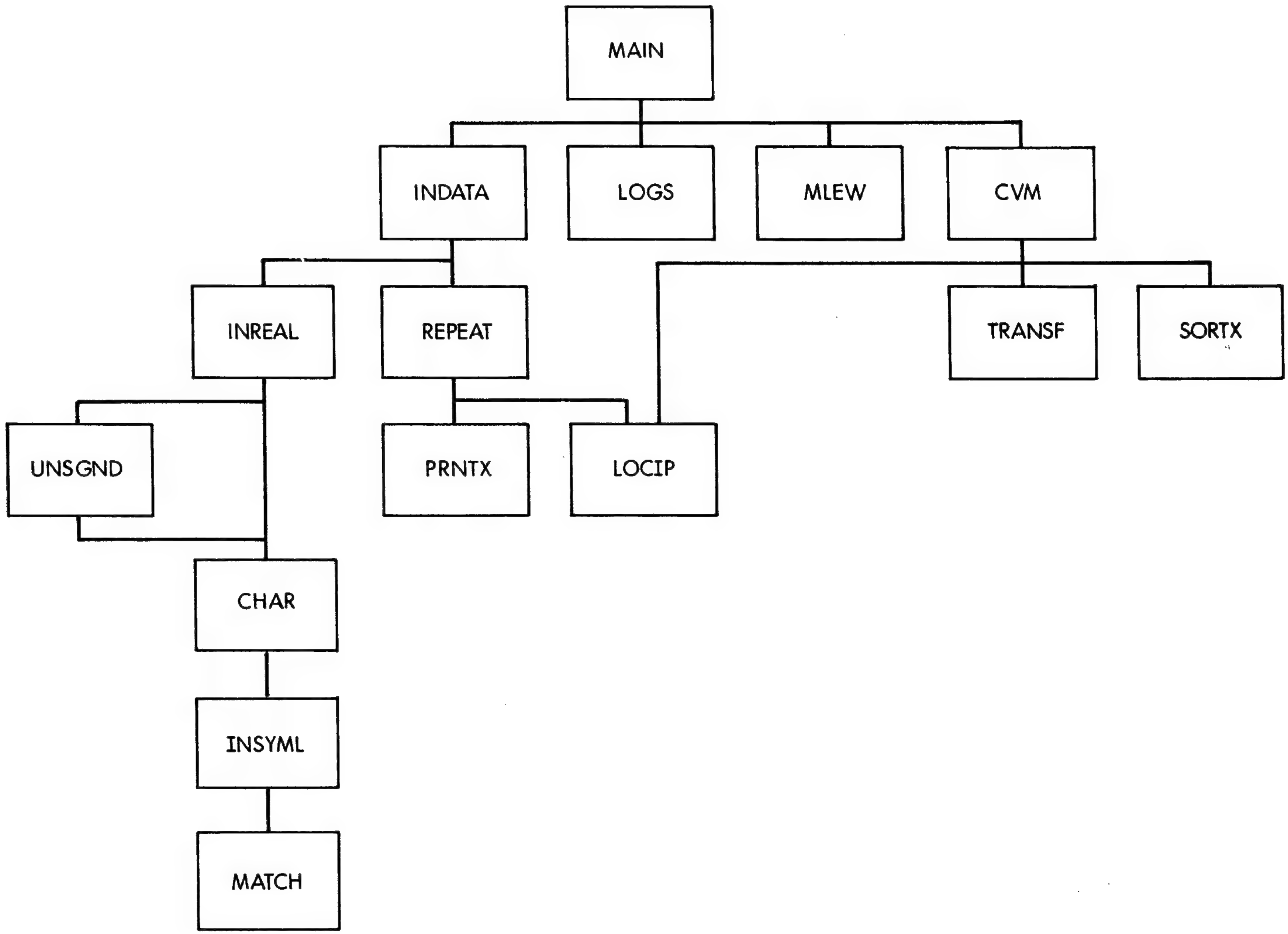

Figure 3.1 Module Organization Chart.

By these actions, all data arrays in all subroutines will be properly resized. Since the program size excluding data arrays, is less than 5,000 words, computer memory requirements can be scaled to problem size through use of this feature.

Also found in the DATA statements at the beginning of the main routine are the unit number for input, IUNIT, and the logical switch ECHO which controls the printing of the input data. Just as the storage allocation values, these values may be changed as needed.

The first major module is for the input of data. The INDATA module reads the beginning and the ending times and the failure times from the input unit, IUNIT. If the logical variable ECHO is true, the submodule REPEAT will print the input, using the LOCIP subroutine to isolate in storage the failures for each system and the PRNTX subroutine to print them. The failure times are stored in a linear array with negative signs appended to the failures associated with even numbered systems. This scheme preserves the identification of the failures with the respective systems without using additional storage.

The free-field reading of data is performed by the INREAL submodule. This submodule, consisting of the routines INREAL, CHAR, INSYML, MATCH and UNSGND, is a translation from ALGOL into FORTRAN of Algorithm 239 of the Association for Computing Machinery (see McKeeman [1964]). Specific details concerning the input arrangement are given in Section 4.

The INDATA subroutine also sets three logical variables depending on the input. If data errors are encountered, the variable NOGOOD is made true. If all systems start at 0.0, then the goodness of fit test will be appropriate and so the variable GOF is set to true. Lastly, when the end of input is reached, the logical variable HALT is returned as true.

The second principal module, LOGS, calculates the logarithms of the beginning and the ending times, and the sum of the logarithms of the failure times. For computational purposes, a beginning time of 0.0 is defined to have a logarithm of 0.0 instead of infinity. Note that failure times of 0.0 are not valid for this model and are flagged as errors by the preceding INDATA module.

The next major module, MLEW, computes the maximum likelihood estimates of the parameters of the Weibull intensity function for the given data, using the formulas discussed in Section 2.1. If unsuccessful, this module will report one of three possible error conditions. The first error message "BETA LESS THAN 0.00000001" indicates that the data should be rechecked for the reasonableness of a very small $\hat{\beta}$. The second error message is "INITIAL ESTIMATE OF BETA IS TOO SMALL." Since the initial estimate of BETA is set to 10 at the start of the MLEW subprogram, this message indicates some pecularity of the data. (In general, $0<\hat{\beta}<10$.) The third message, "STEP-SIZE HAS BECOME INSIGNIFICANT - BETA NOT RESOLVABLE," indicates that the module has gone as far as

possible trying to meet the tolerance set for the difference A-D($\hat{\beta}'$). This tolerance, EPSILN, may be enlarged by changing the assignment statement also located at the beginning of the MLEW subprogram.

The last major module, CVM, performs the Cramér-Von Mises goodness of fit test, as described in Section 2.2. The failure times for each system are located in storage using the LOCIP subroutine, and examined to determine if the testing was time truncated or failure truncated. The failure times are then transformed by the TRANSF subroutine and sorted by the SORTX subroutine. (SORTX is a modification of an utility subprogram described in Campbell, et al., [1970].) The unbiased estimate of β, UNBETA, is calculated next, as explained earlier. The last phase depends on the system starting times. If any starting time is non-zero, the module terminates with a message stating that the Cramér-Von Mises goodness of fit test is not appropriate. Otherwise, the goodness of fit statistic, CM2, is computed and printed.

4. INPUT REQUIREMENTS

As stated previously, the input for this program is free-field. The only requirement regarding spacing is that at least one blank column separate adjacent values. The values must not run together. This means that the program generally takes the same view of the data that a person would, namely, that each cluster of numeric characters constitutes one data value. The only exception to this rule occurs at the boundaries of records. Since the input is treated as a continuous stream, a string of characters beginning in the first column of a record, is considered a continuation of the string of characters ending in the last column of the previous record, if any. Record boundaries are not delimiters; blanks are the only delimiters.

The data required for this program consist of the beginning and ending times of the test period for each system, and the failure times for each system. The arrangement of the input, (which is also stated in the comments of the INDATA subroutine), is by system. The first data value is the beginning time of the first system. The second data value is the ending time of the first system. Next is the failure times for the first system, followed by a negative value to mark the end of the first system. The same pattern, beginning time, ending time, failure times, and negative trailer, is repeated for each subsequent system in the first data case.

Another negative value (making two in a row), signals the end of input of the current data case, and the beginning of the computational procedures. The same arrangement may be repeated for as many cases as desired per program run. When the input routine encounters a negative value after completing a case, (that is, the third negative value in a row), the end of the program run is indicated.

Thus, as a simple example, if one desired to use this program for one run consisting of one case wherein one system experienced seven failures, the input data would be: the beginning time, the ending time, the seven failure times, and three negative values. To demonstrate the latitude of the input requirements, the data for a number of test cases are shown in Appendix B. Notice that any negative value is acceptable as a trailer and that data values may be entered with or without decimal points. Although not shown in the examples, data values may also be in exponential form, that is, containing 'E,' '+' or '-.'

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5. TRANSFERABILITY AND MODIFICATION

Since this program is written in standard FORTRAN, transfer to other computer systems should be straightforward. To assist in the transfer process, Appendix C contains the output produced by the program for the input shown in Appendix B. This output was generated on a Control Data Corporation (CDC) Cyber 76 Computer, using the program exactly as listed in Appendix A. (Note that non-standard PROGRAM statement required by the CDC Cyber.)

The input for these test cases came from records of eighty characters each. If the input record length is other than eighty, two changes may be required. The value of the variable LENGTH and, if necessary, the dimensioned size of the array BUFFER, should be adjusted in the INSYML subroutine.

Alternatively, one could replace the entire INREAL submodule. Although these routines were written to be fully transportable, running time might be saved by using the system defined free-field reading capability of any computer having such a feature. As an example, a substitute for the INREAL submodule, suitable for the CDC Cyber 76, is shown in Figure 5.1. Such substitutes, however, are system dependent and not readily transferable.

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FIGURE 5.1 SUBSTITUTE FOR INREAL SUBMODULE

```
SUBROUTINE INREAL (IU, X)
DOUBLE PRECISION X
READ (IU, *) X
RETURN
END
```

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APPENDIX A

LISTING OF PROGRAM

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```
      PROGRAM MAIN (INPUT=/80,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C        THE ABOVE STATEMENT IS NON-STANDARD, BUT REQUIRED FOR
C        CDC FORTRAN.
C-
C-
C-                 MAIN DRIVER FOR WEIBULL INTENSITY MODEL PARAMETER
C-            ESTIMATION AND GOODNESS OF FIT TEST.
C-
C-                 (VERSION OF 27 JULY 1979)
C-
C-                 INPUT REQUIREMENTS ARE DESCRIBED IN THE 'INDATA'
C-            SUBROUTINE.
C-
C
      DOUBLE PRECISION BETA, SUMLNX
      DOUBLE PRECISION BLOCK(11000)
      LOGICAL ECHO, FAULT, GOF, HALT, NOGOOD
C
      DATA IUNIT /5/
      DATA ECHO /.TRUE./
      DATA NFAIL, NSYS /5000, 1000/
      DATA NTOTAL /11000/
C
      WRITE (6,20)
C
C        ALLOCATE STORAGE BASED ON MAXIMUM NUMBERS OF FAILURES
C             AND SYSTEMS.
      NS2=NSYS*2
      I1=1
      I2=I1+NFAIL
      I3=I2+NS2
      I4=I3+NS2
      ITOTAL=I4+NS2-1
      IF (ITOTAL.LE.NTOTAL) GO TO 10
      WRITE (6,30) ITOTAL,NTOTAL
      STOP
C
C        BEGIN PROCESSING.
   10 CALL INDATA (BLOCK(I1),BLOCK(I2),NOGOOD,GOF,HALT,NFAIL,NSYS,M,K,IU
     1NIT,ECHO)
      IF (HALT) STOP
      IF (NOGOOD) GO TO 10
      CALL LOGS (BLOCK(I1),BLOCK(I2),BLOCK(I4),NFAIL,NSYS,M,K,SUMLNX)
      CALL MLEW (SUMLNX,BLOCK(I2),BLOCK(I3),BLOCK(I4),FAULT,NSYS,M,K,BET
     1A)
      IF (.NOT.FAULT) CALL CVM (BLOCK(I1),BLOCK(I2),NFAIL,NSYS,M,K,BETA,
     1GOF)
      GO TO 10
C
   20 FORMAT (71H1 WEIBULL INTENSITY MODEL PARAMETER ESTIMATION AND GOOD
     1NESS OF FIT TEST/25H0 VERSION OF 27 JULY 1979////)
   30 FORMAT (33H1 AMOUNT OF STORAGE REQUESTED IS ,I6,40H WORDS.  AMOUNT
     1 OF STORAGE AVAILABLE IS ,I5,25H WORDS.  PROGRAM ABORTED./)
      END
```

```
      SUBROUTINE CVM (X,C,NFAIL,NSYS,M,K,BETA,GOF)
COMMENT        THIS SUBROUTINE PERFORMS THE CRAMER-VON MISES GOODNESS
C          OF FIT TEST.
C
      DOUBLE PRECISION X(NFAIL), C(NSYS,2)
      DOUBLE PRECISION BETA, CM2, DM, SUMSQS, TQ, TWOM, UNBETA
      DOUBLE PRECISION TERM, TERM1, TERM2
      LOGICAL GOF
      LOGICAL TIMETR
C
      WRITE (6,60) BETA,M
      IP=0
      IBT=1
      TIMETR=.TRUE.
      N=M
C
      DO 30 J=1,K
      IB=IP+1
      CALL LOCIP (X,NFAIL,N,IP)
      IE=IP
      DO 10 I=IB,IE
C        CHECK FOR FAILURE TRUNCATED TESTING.
      IF (DABS(DABS(X(I))-C(J,2)).LE.1.0D-08) TIMETR=.FALSE.
   10 CONTINUE
      IF (TIMETR) GO TO 20
      IE=IE-1
      M=M-1
      TIMETR=.TRUE.
   20 CONTINUE
      TQ=C(J,2)
      IET=IE
C        TRANSFORM THE FAILURES.
      CALL TRANSF (X,TQ,IB,IBT,IET,NFAIL)
      IBT=IET+1
   30 CONTINUE
C
      DO 40 I=1,M
      X(I)=DABS(X(I))
   40 CONTINUE
C        SORT THE TRANSFORMED FAILURES INTO INCREASING ORDER.
      CALL SORTX (X,M)
C
      DM=DBLE(FLOAT(M))
      TWOM=2.0D0*DM
C        UNBIASED ESTIMATE OF BETA.
      UNBETA=BETA*(DM-1.0D0)/DBLE(FLOAT(N))
      WRITE (6,110) UNBETA
      IF (GOF) GO TO 50
      WRITE (6,100)
      GO TO 70
C
   50 SUMSQS=0.0D0
      DO 60 I=1,M
      TERM1=X(I)**UNBETA
      TERM2=DBLE(FLOAT(2*I-1))/TWOM
      TERM=TERM1-TERM2
      SUMSQS=SUMSQS+TERM**2
```

```
   60 CONTINUE
C           CRAMER-VON MISES STATISTIC.
      CM2=SUMSQS+(1.0D0/(12.0D0*DM))
      WRITE (6,90) CM2,M
C
   70 RETURN
C
   80 FORMAT (42H1 CRAMER - VON MISES GOODNESS OF FIT TEST.///18H0ESTIMA
     1TED BETA = ,1PD15.7/22H0NUMBER OF FAILURES = ,I6)
   90 FORMAT (32H0CRAMER - VON MISES STATISTIC = ,1PD15.7/52H0REJECT THE
     1 WEIBULL INTENSITY MODEL IF THE STATISTIC/48H EXCEEDS THE APPROPRI
     2ATE CRITICAL VALUE FOR M = ,I5/)
  100 FORMAT (77H0THE CRAMER - VON MISES GOODNESS OF FIT TEST IS NOT APP
     1ROPRIATE FOR THIS CASE/58H BECAUSE ONE OR MORE SYSTEMS HAVE NON-ZE
     2RO STARTING TIMES./)
  110 FORMAT (29H0UNBIASED ESTIMATE OF BETA = ,1PD15.7////)
      END
```

```
      SUBROUTINE INDATA (X,C,NOGOOD,GOF,HALT,NFAIL,NSYS,M,K,IUNIT,ECHO)
COMMENT        THIS SUBROUTINE READS IN THE BEGINNING AND ENDING TIMES,
C         AND THE FAILURE TIMES.
C
C         THE ARRANGEMENT OF INPUT IS AS FOLLOWS:
C
C              BEGINNING AND ENDING TIMES FOR FIRST SYSTEM, FAILURE
C                   TIMES FOR FIRST SYSTEM, NEGATIVE VALUE AS TRAILER.
C              BEGINNING AND ENDING TIMES FOR SECOND SYSTEM, FAILURE
C                   TIMES FOR SECOND SYSTEM, NEGATIVE VALUE FOR TRAILER.
C              ...
C              ...
C              ...
C              BEGINNING AND ENDING TIMES FOR K-TH SYSTEM, FAILURE
C                   TIMES FOR K-TH SYSTEM, NEGATIVE VALUE AS TRAILER.
C              NEGATIVE VALUE TO MARK END OF CASE.
C                   (REPEAT ABOVE FOR AS MANY CASES AS NEEDED.)
C              NEGATIVE VALUE TO MARK END OF RUN.
C
C         INPUT IS FREE-FIELD, REQUIRING ONLY THAT AT LEAST ONE BLANK
C         COLUMN SEPARATE ADJACENT VALUES.
C
      DOUBLE PRECISION X(NFAIL), C(NSYS,2)
      LOGICAL ECHO, GOF, HALT, NOGOOD
C
      GOF=.TRUE.
      HALT=.FALSE.
      NOGOOD=.FALSE.
      WRITE (6,130)
C
      J=1
      I=1
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                   BEGIN INPUT CYCLE.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   10 CALL INREAL (IUNIT,C(J,1))
C                   NEGATIVE VALUE TO MARK THE END OF THIS CASE.
      IF (C(J,1).LT.0.0D0) GO TO 50
      CALL INREAL (IUNIT,C(J,2))
      IF (DABS(C(J,1)).GT.1.0D-08) GOF=.FALSE.
      J=J+1
      IF (J.LE.NSYS) GO TO 20
      WRITE (6,100) J
      NOGOOD=.TRUE.
C
   20 CALL INREAL (IUNIT,X(I))
C                   NEGATIVE VALUE TO MARK THE END OF THIS SYSTEM.
      IF (X(I).LT.0.0D0) GO TO 10
      IF (X(I).GT.1.0D-15) GO TO 30
      WRITE (6,110)
      NOGOOD=.TRUE.
C
C                   EACH FAILURE MUST FALL WITHIN THE TEST PERIOD.
   30 IF (C(J-1,1).LE.X(I).AND.X(I).LE.C(J-1,2)) GO TO 40
      WRITE (6,120) X(I),C(J-1,1),C(J-1,2)
      NOGOOD=.TRUE.
   40 IF (MOD(J,2).EQ.0) X(I)=-X(I)
```

```
      I=I+1
      IF (I.LE.NFAIL) GO TO 20
      WRITE (6,99) I
      NOGOOD=.TRUE.
      GO TO 20
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                    END OF INPUT CYCLE.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   50 M=I-1
      IF (M.LE.0) GO TO 60
C                    TOTAL NUMBER OF FAILURES.
      WRITE (6,70) M
      K=J-1
C                    TOTAL NUMBER OF SYSTEMS.
      WRITE (6,80) K
      IF (ECHO) CALL REPEAT (X,C,NFAIL,NSYS,M,K)
      RETURN
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                    END OF RUN.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   60 HALT=.TRUE.
      WRITE (6,140)
      RETURN
C
   70 FORMAT (28HOTOTAL NUMBER OF FAILURES = ,I5)
   80 FORMAT (28HOTOTAL NUMBER OF SYSTEMS  = ,I5)
   90 FORMAT (18HO INDATA ERROR -- ,I6,22H IS TOO MANY FAILURES./)
  100 FORMAT (18HO INDATA ERROR -- ,I6,21H IS TOO MANY SYSTEMS./)
  110 FORMAT (52HO INDATA ERROR -- A FAILURE AT 0.0000000 WAS INPUT. /71
     1HO THE PROBABILITY OF SUCH A FAILURE TIME IS 0.0 ACCORDING TO THE
     2MODEL./)
  120 FORMAT (33HO INDATA ERROR -- THE FAILURE AT ,1PD10.3/44H  DOES NOT
     1 FALL WITHIN THE TEST PERIOD FROM ,1PD10.3,4H TO ,1PD10.3/)
  130 FORMAT (19H1 DATA INPUT PHASE.//)
  140 FORMAT (28HO PROGRAM RUN ENDS NORMALLY./1H1)
      END
```

```
      SUBROUTINE LOCIP (X,NFAIL,M,IP)
COMMENT        THIS SUBROUTINE LOCATES THE POSITION OF THE LAST FAILURE
C         ASSOCIATED WITH THE SYSTEM WHICH HAD FAILURE 'X(IP)'.   ON
C         RETURN, 'IP' INDEXES THIS LAST FAILURE.
C
      DOUBLE PRECISION X(NFAIL)
C
      IB=IP+1
      MM1=M-1
      DO 10 I=IB,MM1
      IF ((X(I).LT.0.0D0.AND.X(I+1).LT.0.0D0).OR.(X(I).GE.0.0D0.AND.X(I+
     1 1).GE.0.0D0)) GO TO 10
      IP=I
      RETURN
   10 CONTINUE
      IP=M
      RETURN
      END
```

```
      SUBROUTINE LOGS (X,C,CLN,NFAIL,NSYS,M,K,SUMLNX)
COMMENT        THIS SUBROUTINE TAKES LOGARITHMS.
C
      DOUBLE PRECISION X(NFAIL), C(NSYS,2), CLN(NSYS,2)
      DOUBLE PRECISION SUMLNX
C
C                     LOGARITHMS OF BEGINNING AND ENDING TIMES.
      DO 20 I=1,K
      CLN(I,2)=DLOG(C(I,2))
      IF (C(I,1).LE.0.0D0) GO TO 10
      CLN(I,1)=DLOG(C(I,1))
      GO TO 20
   10 C(I,1)=0.0D0
      CLN(I,1)=0.0D0
   20 CONTINUE
C
C                     SUM OF LOGARITHMS OF FAILURES.
      SUMLNX=0.0D0
      DO 30 I=1,M
      SUMLNX=SUMLNX+DLOG(DABS(X(I)))
   30 CONTINUE
      RETURN
C
      END
```

```
      SUBROUTINE MLEW (SUMLNX,C,CB,CLN,NOGOOD,NSYS,M,K,BETA)
C-
C-
C-       ESTIMATES OF PARAMETERS OF THE WEIBULL INTENSITY MODEL.
C-
C-               THIS SUBROUTINE ESTIMATES BETA AND LAMBDA OF THE
C-    WEIBULL INTENSITY FUNCTION  R(X)=LAMBDA*BETA*X**(BETA-1.0)
C-               BETA IS DETERMINED BY AN ITERATIVE PROCESS WHICH
C-    EXAMINES THE SIGNED DIFFERENCE OF A CONSTANT MINUS A FUNCTION OF
C-    BETA AS BETA IS DECREASED FROM A LARGE INITIAL ESTIMATE BY
C-    NON-POSITIVE POWERS OF 10.0 UNTIL AN EPSILON TOLERANCE IS
C-    SATISFIED OR BETA IS LESS THAN 0.00000001 IN VALUE.
C-               LAMBDA IS CALCULATED BASED ON BETA.
C
      DOUBLE PRECISION C(NSYS,2), CB(NSYS,2), CLN(NSYS,2)
      DOUBLE PRECISION BETA, LAMBDA, EPSILN
      DOUBLE PRECISION DENOM, DENOM1, DENOM2, TOP, TOP1, TOP2
      DOUBLE PRECISION A, ABDI, ADJ, D, DIFF, TOTFAL
      DOUBLE PRECISION SUMLNX
      LOGICAL NOGOOD
C
      WRITE (6,110)
      BETA=1.0D+01
      EPSILN=1.0D-05
      TOTFAL=DBLE(FLOAT(M))
      NPDIFF=0
      NOGOOD=.FALSE.
C
C                   CONSTANT NOT INVOLVING BETA.
      A=SUMLNX/TOTFAL
      WRITE (6,130) A
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                   BEGIN ITERATION PROCEDURE.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      ADJ=1.0D0
      IZERO=0
      WRITE (6,150)
C
   10 TOP1=0.0D0
      TOP2=0.0D0
      DENOM1=0.0D0
      DENOM2=0.0D0
      DO 20 I=1,K
      DO 20 J=1,2
      CB(I,J)=C(I,J)**BETA
   20 CONTINUE
C
      DO 30 I=1,K
      TOP1=TOP1+CB(I,1)*CLN(I,1)
      TOP2=TOP2+CB(I,2)*CLN(I,2)
      DENOM1=DENOM1+CB(I,1)
      DENOM2=DENOM2+CB(I,2)
   30 CONTINUE
C
      TOP=TOP2-TOP1
      DENOM=DENOM2-DENOM1
      D=(TOP/DENOM)-1.0D0/BETA
```

```
      DIFF=A-D
      LAMBDA=TOTFAL/DENOM
      WRITE (6,120) BETA,D,DIFF,LAMBDA
      ABDI=DABS(DIFF)
      IF (ABDI.LE.EPSILN) GO TO 50
      IF (DIFF.GT.0.0D0) GO TO 40
      NPDIFF=0
      BETA=BETA-ADJ
      IF (BETA.LE.1.0D-15) GO TO 60
      GO TO 10
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C           BETA TOO SMALL -- DECREASE STEP SIZE AND USE PREVIOUS BETA.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   40 BETA=BETA+ADJ
      NPDIFF=NPDIFF+1
      IF (NPDIFF.GT.10) GO TO 70
      ADJ=1.0D-1*ADJ
      IF (DABS(DLOG10(DABS(BETA))-DLOG10(ADJ)).GT.1.5D+1) GO TO 80
      BETA=BETA-ADJ
      GO TO 10
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                       EPSILON TOLERANCE MET.
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   50 WRITE (6,140) BETA,LAMBDA,ABDI,EPSILN,ADJ
      GO TO 100
C
   60 IZERO=IZERO+1
      IF (IZERO.LE.8) GO TO 40
      WRITE (6,160)
      GO TO 90
   70 WRITE (6,170)
      GO TO 90
   80 WRITE (6,180)
   90 NOGOOD=.TRUE.
C
  100 RETURN
C
C
  110 FORMAT (65H1 ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY
     1 FUNCTION./)
  120 FORMAT (1H ,4(1PD16.9,4X))
  130 FORMAT (35HCCONSTANT NOT INVOLVING BETA:  A = ,1PD15.7/)
  140 FORMAT (30H1THE FINAL ESTIMATE OF BETA = ,1PD15.7//32H THE FINAL E
     1STIMATE OF LAMBDA = ,1PD15.7//16H CONVERGENCE TO ,1PD15.7/30H WHIC
     2H IS LESS THAN EPSILON = ,1PD15.7//24H THE FINAL STEP SIZE IS ,1PD
     315.7/)
  150 FORMAT (1H0/16H0 ESTIMATED BETA,5X,15H FUNCTION D(B'),8X,10H A - D
     1(B'),6X,17H ESTIMATED LAMBDA/)
  160 FORMAT (41H0 MLEW ERROR -- BETA LESS THAN 0.00000001)
  170 FORMAT (53H0 MLEW ERROR -- INITIAL ESTIMATE OF BETA IS TOO SMALL)
  180 FORMAT (50H0 MLEW ERROR -- STEP-SIZE HAS BECOME INSIGNIFICANT/20H
     1BETA NOT RESOLVABLE/)
      END
```

```
      SUBROUTINE PRNTX (X,NFAIL,IB,IE)
COMMENT       THIS SUBROUTINE PRINTS THE FAILURES 'X(IB)' THROUGH
C         'X(IE)'.
C
      DOUBLE PRECISION X(NFAIL)
      DOUBLE PRECISION XTEMP(5)
      DATA L /5/
C
      IT=0
      DO 20 I=IB,IE
      IT=IT+1
      XTEMP(IT)=DABS(X(I))
      IF (I.EQ.IE) GO TO 10
      IF (IT.LT.L) GO TO 20
   10 WRITE (6,30) (XTEMP(J),J=1,IT)
      IT=0
   20 CONTINUE
C
      RETURN
C
   30 FORMAT (1H ,30X,1P5D10.3)
      END
```

```
      SUBROUTINE REPEAT (X,C,NFAIL,NSYS,M,K)
COMMENT        THIS SUBROUTINE REPEATS THE INPUT DATA.
C
      DOUBLE PRECISION X(NFAIL), C(NSYS,2)
C
      WRITE (6,20)
      IP=0
C
      DO 10 J=1,K
      WRITE (6,30) C(J,1),C(J,2)
      IB=IP+1
      CALL LOCIP (X,NFAIL,M,IP)
      IE=IP
      CALL PRNTX (X,NFAIL,IB,IE)
   10 CONTINUE
C
      RETURN
C
   20 FORMAT (1H0/34HOSYSTEM STARTING AND ENDING TIMES./1H0,35X,10H FAIL
     1URES./)
   30 FORMAT (1H ,1P2D12.3)
      END
```

```
      SUBROUTINE SORTX (X,N)
COMMENT       THIS SUBROUTINE SORTS THE VECTOR X INTO INCREASING ORDER.
C
      DOUBLE PRECISION X(N)
      M=N
   10 M=M/2
      IF (M.EQ.0) RETURN
      K=N-M+1
      J=1
   20 I=J
   30 L=I+M
      IF (X(I).GT.X(L)) GO TO 50
   40 J=J+1
      IF (J-K) 20,10,10
   50 T=X(L)
      X(L)=X(I)
      X(I)=T
      I=I-M
      IF (I) 40,40,30
      END
```

```
      SUBROUTINE TRANSF (X,TQ,IB,IBT,IET,NFAIL)
COMMENT        THIS SUBROUTINE TRANSFORMS THE FAILURE TIMES.
C
      DOUBLE PRECISION X(NFAIL), TQ
C
      IF (IET.LE.0) RETURN
      J=IB
      DO 10 I=IBT,IET
      X(I)=X(J)/TQ
      J=J+1
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INREAL (CHANNL,DESTIN)
COMMENT        FREE FIELD READ.
C        (A FORTRAN TRANSLATION OF ACM ALGORITHM 239.)
C
C              EACH CALL OF THIS SUBROUTINE WILL READ ONE REAL NUMBER
C        FROM UNIT 'CHANNL', CONVERT IT, AND STORE IT IN 'DESTIN'.
C
      INTEGER CHANNL
      DOUBLE PRECISION DESTIN
      REAL SIG, FP, D
      INTEGER ESIG, EP, IP, CH
      INTEGER CHAR, UNSGND
C
      SIG=1.0
      EP=0
      FP=0
C
   10 CH=CHAR(CHANNL)
C         SUPPRESS INITIAL BLANKS.
      IF (CH.EQ.14) GO TO 10
C         12 = '+' AND 11 = '-'.
      IF (CH.NE.12) GO TO 20
      CH=CHAR(CHANNL)
      GO TO 30
   20 IF (CH.NE.11) GO TO 30
      SIG=-1.0
      CH=CHAR(CHANNL)
   30 CONTINUE
      IF (CH.GT.10) GO TO 70
      IF (CH.GE.10) GO TO 40
      IP=UNSGND(CHANNL,CH)
      GO TO 50
   40 CONTINUE
      IP=0
   50 CONTINUE
      IF (CH.NE.10) GO TO 100
      CH=CHAR(CHANNL)
      FP=0
      IF (CH.GE.10) GO TO 100
      D=0.1
C
   60 FP=FP+FLOAT(CH)*D
      D=D*0.1
      CH=CHAR(CHANNL)
      IF (CH.LT.10) GO TO 60
      GO TO 100
   70 CONTINUE
      IF (CH.NE.13) GO TO 80
      IP=1
      GO TO 90
   80 CONTINUE
      WRITE (6,180)
      STOP
   90 CONTINUE
  100 CONTINUE
C
      IF (CH.NE.13) GO TO 160
```

```
      CH=CHAR(CHANNL)                                                   INREL580
      ESIG=1                                                            INREL590
      IF (CH.NE.12.AND.CH.NE.14) GO TO 110                              INREL600
      CH=CHAR(CHANNL)                                                   INREL610
      GO TO 130                                                         INREL620
  110 CONTINUE                                                          INREL630
      IF (CH.NE.11) GO TO 120                                           INREL640
C                     NEGATIVE EXPONENT.                                INREL650
      ESIG=-1                                                           INREL660
      CH=CHAR(CHANNL)                                                   INREL670
  120 CONTINUE                                                          INREL680
  130 CONTINUE                                                          INREL690
      IF (CH.GE.10) GO TO 140                                           INREL700
      EP=UNSGND(CHANNL,CH)*ESIG                                         INREL710
      GO TO 150                                                         INREL720
  140 CONTINUE                                                          INREL730
      WRITE (6,190)                                                     INREL740
      STOP                                                              INREL750
  150 CONTINUE                                                          INREL760
  160 CONTINUE                                                          INREL770
C                                                                       INREL780
      IF (CH.NE.14) GO TO 170                                           INREL790
C                                                                       INREL800
      DESTIN=DBLE(SIG*(FLOAT(IP)+FP)*(10.0**EP))                        INREL810
C                                                                       INREL820
      RETURN                                                            INREL830
  170 WRITE (6,200)                                                     INREL840
      STOP                                                              INREL850
C                                                                       INREL860
  180 FORMAT (36H0 INREAL ERROR -- CH OUT OF RANGE.  /)                 INREL870
  190 FORMAT (41H0 INREAL ERROR -- EXPONENT NOT DIGIT.     /)           INREL880
  200 FORMAT (53H0 INREAL ERROR -- NO BLANK FOUND BETWEEN DATA VALUES./)INREL890
      END                                                               INREL900
```

```
      INTEGER FUNCTION CHAR (CHANNL)
COMMENT          'CHAR' RETURNS AN INTEGER VALUE FOR THE NEXT CHARACTER
C          ON UNIT 'CHANNL'.
C
      INTEGER C
      INTEGER CHANNL
      INTEGER STRING(15)
      DATA STRING(1), STRING(2), STRING(3), STRING(4), STRING(5), STRING
     1(6), STRING(7), STRING(8), STRING(9), STRING(10), STRING(11), STRI
     2NG(12), STRING(13), STRING(14), STRING(15) /1H0, 1H1, 1H2, 1H3, 1H
     34, 1H5, 1H6, 1H7, 1H8, 1H9, 1H., 1H-, 1H+, 1HE, 1H /
      DATA LSTR /15/
      CALL INSYML (CHANNL,STRING,LSTR,C)
C          IS CHARACTER LEGAL?
      IF (C.LE.0) GO TO 10
      CHAR=C-1
      RETURN
   10 WRITE (6,20)
      STOP
C
   20 FORMAT (58H0 CHAR ERROR -- ILLEGAL INPUT CHARACTER.  PROGRAM ABORT
     1ED./)
      END
```

```
      SUBROUTINE INSYML (IUNIT,STRING,LSTR,I)
COMMENT        THIS SUBROUTINE EXAMINES THE NEXT CHARACTER ON 'IUNIT'
C         AND DETERMINES ITS POSITION NUMBER 'I' WITHIN THE 'STRING' OF
C         LENGTH 'LSTR'.
C
      INTEGER STRING(LSTR)
      INTEGER BUFFER(160)
      DATA IP /0/
      DATA LENGTH /80/
C
      IF (IP.NE.0) GO TO 10
C              FILL INPUT BUFFER.
      READ (IUNIT,20) (BUFFER(J),J=1,LENGTH)
   10 CONTINUE
      IP=IP+1
      IC=IP
C         MATCH THE CHARACTER.
      CALL MATCH (BUFFER(IC),STRING,LSTR,I)
C         IF POINTER 'IP' HAS REACHED THE END OF A LINE, RESET IT.
      IF (IP.EQ.LENGTH) IP=0
C
      RETURN
C
   20 FORMAT (128A1)
      END
```

```
      SUBROUTINE MATCH (CHAR,STRING,LSTR,IP)
COMMENT        THIS SUBROUTINE FINDS THE POSITION 'IP' OF 'CHAR' IN
C         'STRING' WHICH HAS A LENGTH OF 'LSTR'.
C
      INTEGER CHAR, STRING(LSTR)
      IP=0
      DO 10 I=1,LSTR
      IF (STRING(I).NE.CHAR) GO TO 10
      IP=I
      GO TO 20
   10 CONTINUE
      WRITE (6,30) CHAR
   20 RETURN
C
   30 FORMAT (31H0 MATCH ERROR -- THE CHARACTER ,A1,16H IS NOT MATCHED./
     1)
      END
```

```
      INTEGER FUNCTION UNSGND (CHANNL,CH)
COMMENT        THIS FUNCTION RETURNS THE NEXT UNSIGNED INTEGER FROM
C          'CHANNL'.
C
      INTEGER CHANNL, CH
      INTEGER CHAR
      INTEGER U
      U=0
   10 U=10*U+CH
      CH=CHAR(CHANNL)
      IF (CH.LT.10) GO TO 10
      UNSGND=U
      RETURN
      END
```

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APPENDIX B

INPUT FOR TEST CASES

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INPUT DATA FOR TEST CASES

```
  1.0  100.0  32.  44.  56.  75.  95.  -99.  -99.
12.2  45.3  10.0  14.5  16.8  457.9  -99 -99
  0.0  3256.3  .7  3.7  13.2  17.6  54.5  99.2  112.2  120.9  151.0  163.0
 174.5  191.6  282.8
 355.2  486.3  490.5  513.3  558.4  678.1  688.0  785.9  887.0  1010.7
  1029.1  1034.4  1136.1  1178.9  1259.7  1297.9  1419.7  1571.7
1629.8  1702.3  1928.9  2072.3  2525.2  2928.5  3016.4  3181.0
 3256.3
 -99.  -99.
  0.0  79.0  0.0  20  45.  62  64  68  76  -8 -7
  456.  789.  456  456.1  457  458  489  -99  -99
   0.0  197.2  4.3  4.4  10.2  23.5  23.8  26.4  74.0  77.1  92.1  197.2
-999.
   0.0  190.8  0.1  5.6  18.6  19.5  24.2  26.7  45.1  45.8  75.7  79.7  98.6
               120.1  161.8  180.6  190.8
   -999
   0.0  195.8  8.4  32.5  44.7  48.4  50.6  73.6  98.7  112.2  129.8  136.0
               195.8
   -999
   -999
0.0  800.0  45.  456.  467.  477.  484.  492.
 0.12  564.0  65.0 78. 89. 99.1 -99 -99
  -99
```

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APPENDIX C

OUTPUT FOR TEST CASES

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WEIBULL INTENSITY MODEL PARAMETER ESTIMATION AND GOODNESS OF FIT TEST

VERSION OF 27 JULY 1979

```
DATA INPUT PHASE.

TOTAL NUMBER OF FAILURES =     5

TOTAL NUMBER OF SYSTEMS  =     1

SYSTEM STARTING AND ENDING TIMES.
                                        FAILURES.
   1.000D+00   1.000D+02
                                    3.200D+01 4.400D+01 5.600D+01 7.500D+01 9.500D+01
```

ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY FUNCTION.

CONSTANT NOT INVOLVING BETA: A = 4.0293284D+00

ESTIMATED BETA	FUNCTION D(B')	A - D(B')	ESTIMATED LAMBDA
1.000000000D+01	4.505170186D+00	-4.758417395D-01	5.000000000D-20
9.000000000D+00	4.494059075D+00	-4.647306284D-01	5.000000000D-18
8.000000000D+00	4.480170186D+00	-4.508417395D-01	5.000000000D-16
7.000000000D+00	4.462313043D+00	-4.329845966D-01	5.000000000D-14
6.000000000D+00	4.438503519D+00	-4.091750728D-01	5.000000000D-12
5.000000000D+00	4.405170186D+00	-3.758417399D-01	5.000000001D-10
4.000000000D+00	4.355170232D+00	-3.258417855D-01	5.000000500D-08
3.000000000D+00	4.271841458D+00	-2.425130113D-01	5.000050000D-06
2.000000000D+00	4.105630749D+00	-7.630230255D-02	5.000500050D-04
1.000000000D+00	3.651687057D+00	3.776413900D-01	5.050505051D-02
1.900000000D+00	4.079584382D+00	-5.025593598D-02	7.925722105D-04
1.800000000D+00	4.050771688D+00	-2.144324100D-02	1.256258774D-03
1.700000000D+00	4.018768973D+00	1.055947321D-02	1.991328615D-03
1.790000000D+00	4.047722570D+00	-1.839412345D-02	1.315480002D-03
1.780000000D+00	4.044641152D+00	-1.531270529D-02	1.377493745D-03
1.770000000D+00	4.041526963D+00	-1.219851680D-02	1.442431753D-03
1.760000000D+00	4.038379527D+00	-9.051080574D-03	1.510432003D-03
1.750000000D+00	4.035198358D+00	-5.869911384D-03	1.581638988D-03
1.740000000D+00	4.031982963D+00	-2.654516074D-03	1.656204028D-03
1.730000000D+00	4.028732840D+00	5.956065495D-04	1.734285593D-03
1.739000000D+00	4.031659521D+00	-2.331074881D-03	1.663851262D-03
1.738000000D+00	4.031335732D+00	-2.007285916D-03	1.671533818D-03
1.737000000D+00	4.031011595D+00	-1.683148672D-03	1.679251859D-03
1.736000000D+00	4.030687109D+00	-1.358662642D-03	1.687005549D-03
1.735000000D+00	4.030362274D+00	-1.033827318D-03	1.694795052D-03
1.734000000D+00	4.030037089D+00	-7.086421920D-04	1.702620534D-03
1.733000000D+00	4.029711553D+00	-3.831067529D-04	1.710482162D-03
1.732000000D+00	4.029385667D+00	-5.722049074D-05	1.718380103D-03
1.731000000D+00	4.029059429D+00	2.690171060D-04	1.726314523D-03
1.731900000D+00	4.029353059D+00	-2.461254957D-05	1.719171900D-03
1.731800000D+00	4.029320448D+00	7.998905460D-06	1.719964063D-03

```
THE FINAL ESTIMATE OF BETA =    1.7318000D+00

THE FINAL ESTIMATE OF LAMBDA =    1.7199641D-03

CONVERGENCE TO    7.9989355D-06
WHICH IS LESS THAN EPSILON =    1.0000000D-05

THE FINAL STEP SIZE IS    1.0000000D-04
```

```
CRAMER - VON MISES GOODNESS OF FIT TEST.


ESTIMATED BETA =   1.7318000D+00

NUMBER OF FAILURES =      5

UNBIASED ESTIMATE OF BETA =   1.3854400D+00



THE CRAMER - VON MISES GOODNESS OF FIT TEST IS NOT APPROPRIATE FOR THIS CASE
BECAUSE ONE OR MORE SYSTEMS HAVE NON-ZERO STARTING TIMES.
```

```
DATA INPUT PHASE.


INDATA ERROR -- THE FAILURE AT  1.000D+01
DOES NOT FALL WITHIN THE TEST PERIOD FROM  1.220D+01 TO  4.530D+01

INDATA ERROR -- THE FAILURE AT  4.579D+02
DOES NOT FALL WITHIN THE TEST PERIOD FROM  1.220D+01 TO  4.530D+01

TOTAL NUMBER OF FAILURES =     4

TOTAL NUMBER OF SYSTEMS  =     1


SYSTEM STARTING AND ENDING TIMES.
                                          FAILURES.

   1.220D+01   4.530D+01
                                    1.000D+01 1.450D+01 1.680D+01 4.579D+02
```

DATA INPUT PHASE.

TOTAL NUMBER OF FAILURES = 40

TOTAL NUMBER OF SYSTEMS = 1

SYSTEM STARTING AND ENDING TIMES.

FAILURES.

0. 3.256D+03

7.000D-01	3.700D+00	1.320D+01	1.760D+01	5.450D+01
9.920D+01	1.122D+02	1.209D+02	1.510D+02	1.630D+02
1.745D+02	1.916D+02	2.828D+02	3.552D+02	4.863D+02
4.905D+02	5.133D+02	5.584D+02	6.781D+02	6.880D+02
7.859D+02	8.870D+02	1.011D+03	1.029D+03	1.034D+03
1.136D+03	1.179D+03	1.260D+03	1.298D+03	1.420D+03
1.572D+03	1.630D+03	1.702D+03	1.929D+03	2.072D+03
2.525D+03	2.929D+03	3.016D+03	3.181D+03	3.256D+03

ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY FUNCTION.

CONSTANT NOT INVOLVING BETA: A = 6.0464988D+00

ESTIMATED BETA	FUNCTION D(B')	A - D(B')	ESTIMATED LAMBDA
1.0000000000D+01	7.9883468600D+00	-1.9418481010D+00	2.9841173600D-34
9.0000000000D+00	7.9772357490D+00	-1.9307369900D+00	9.7171813580D-31
8.0000000000D+00	7.9633468600D+00	-1.9168481010D+00	3.1642057660D-27
7.0000000000D+00	7.9454897180D+00	-1.8989909580D+00	1.0303603230D-23
6.0000000000D+00	7.9216801940D+00	-1.8751814340D+00	3.3551623210D-20
5.0000000000D+00	7.8883468600D+00	-1.8418481010D+00	1.0925415070D-16
4.0000000000D+00	7.8383468600D+00	-1.7918481010D+00	3.5576429080D-13
3.0000000000D+00	7.7550135270D+00	-1.7085147680D+00	1.1584752600D-09
2.0000000000D+00	7.5883468600D+00	-1.5418481010D+00	3.7723429900D-06
1.0000000000D+00	7.0883468600D+00	-1.0418481010D+00	1.2283880480D-02
9.0000000000D-01	6.9772357490D+00	-9.3073698980D-01	2.7580873920D-02
8.0000000000D-01	6.8383468600D+00	-7.9184810090D-01	6.1927060240D-02
7.0000000000D-01	6.6597754320D+00	-6.1327667230D-01	1.3904420870D-01
6.0000000000D-01	6.4216801940D+00	-3.7518143420D-01	3.1219457050D-01
5.0000000000D-01	6.0883468600D+00	-4.1848100910D-02	7.0096734530D-01
4.0000000000D-01	5.5883468600D+00	4.5815189910D-01	1.5738749660D+00
4.9000000000D-01	6.0475305340D+00	-1.0317743820D-03	7.6002001730D-01
4.8000000000D-01	6.0050135270D+00	4.1485232420D-02	8.2404755450D-01
4.8900000000D-01	6.0433570850D+00	3.1416741390D-03	7.6619225070D-01
4.8990000000D-01	6.0471139560D+00	-6.1519623820D-04	7.6063499650D-01
4.8980000000D-01	6.0466972080D+00	-1.9844799300D-04	7.6125047340D-01
4.8970000000D-01	6.0462802890D+00	2.1847045760D-04	7.6186644820D-01
4.8979000000D-01	6.0466555230D+00	-1.5676380890D-04	7.6131204840D-01
4.8978000000D-01	6.0466138370D+00	-1.1507792270D-04	7.6137362850D-01
4.8977000000D-01	6.0465721500D+00	-7.3390334170D-05	7.6143521350D-01
4.8976000000D-01	6.0465304610D+00	-3.1701043280D-05	7.6149680350D-01
4.8975000000D-01	6.0464887730D+00	9.9899500840D-06	7.6155839850D-01

```
THE FINAL ESTIMATE OF BETA =    4.8975000D-01

THE FINAL ESTIMATE OF LAMBDA =    7.6155840D-01

CONVERGENCE TO    9.9899501D-06
WHICH IS LESS THAN EPSILON =    1.0000000D-05

THE FINAL STEP SIZE IS    1.0000000D-05
```

```
CRAMER - VON MISES GOODNESS OF FIT TEST.


ESTIMATED BETA =    4.8975000D-01

NUMBER OF FAILURES =      40

UNBIASED ESTIMATE OF BETA =    4.6526250D-01



CRAMER - VON MISES STATISTIC =    6.8281012D-02

REJECT THE WEIBULL INTENSITY MODEL IF THE STATISTIC
EXCEEDS THE APPROPRIATE CRITICAL VALUE FOR M =    39
```

```
DATA INPUT PHASE.


INDATA ERROR -- A FAILURE AT 0.0000000 WAS INPUT.
THE PROBABILITY OF SUCH A FAILURE TIME IS 0.0 ACCORDING TO THE MODEL.

TOTAL NUMBER OF FAILURES =      7
TOTAL NUMBER OF SYSTEMS  =      1


SYSTEM STARTING AND ENDING TIMES.
                                           FAILURES.
   0.           7.900D+01
                                 0.
```

```
DATA INPUT PHASE.

TOTAL NUMBER OF FAILURES =      5
TOTAL NUMBER OF SYSTEMS  =      1

SYSTEM STARTING AND ENDING TIMES.
                                        FAILURES.
   4.560D+02   7.890D+02
                                    4.560D+02 4.561D+02 4.570D+02 4.580D+02 4.890D+02
```

ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY FUNCTION.

CONSTANT NOT INVOLVING BETA: A = 6.1378240D+00

ESTIMATED BETA	FUNCTION D(B')	A - D(B')	ESTIMATED LAMBDA
1.000000000D+01	6.573055529D+00	-4.352315370D-01	5.370435537D-29
9.000000000D+00	6.563628256D+00	-4.258042640D-01	4.250232894D-26
8.000000000D+00	6.552677307D+00	-4.148533158D-01	3.371273954D-23
7.000000000D+00	6.539978097D+00	-4.021541058D-01	2.684647236D-20
6.000000000D+00	6.525323229D+00	-3.874992378D-01	2.152792775D-17
5.000000000D+00	6.508556971D+00	-3.707329793D-01	1.747965628D-14
4.000000000D+00	6.489619802D+00	-3.517958100D-01	1.452242925D-11
3.000000000D+00	6.468596384D+00	-3.307723920D-01	1.261510485D-08
2.000000000D+00	6.445754082D+00	-3.079300902D-01	1.206025302D-05
1.000000000D+00	6.421555273D+00	-2.837312818D-01	1.501501502D-02
9.000000000D-01	6.419083888D+00	-2.812598969D-01	3.170401197D-02
8.000000000D-01	6.416605856D+00	-2.787818649D-01	6.776262633D-02
7.000000000D-01	6.414121892D+00	-2.762979005D-01	1.470949998D-01
6.000000000D-01	6.411632718D+00	-2.738087267D-01	3.258760473D-01
5.000000000D-01	6.409139065D+00	-2.713150738D-01	7.423918966D-01
4.000000000D-01	6.406641670D+00	-2.688176787D-01	1.761304281D+00
3.000000000D-01	6.404141275D+00	-2.663172833D-01	4.456108471D+00
2.000000000D-01	6.401638625D+00	-2.638146339D-01	1.268005091D+01
1.000000000D-01	6.399134472D+00	-2.613104802D-01	4.809680779D+01
9.000000000D-02	6.398884003D+00	-2.610600110D-01	5.697237019D+01
8.000000000D-02	6.398633527D+00	-2.608095350D-01	6.832918901D+01
7.000000000D-02	6.398383045D+00	-2.605590530D-01	8.325044844D+01
6.000000000D-02	6.398132557D+00	-2.603085657D-01	1.035429781D+02
5.000000000D-02	6.397882066D+00	-2.600580740D-01	1.324610187D+02
4.000000000D-02	6.397631570D+00	-2.598075784D-01	1.765156468D+02
3.000000000D-02	6.397381071D+00	-2.595570799D-01	2.509030623D+02
2.000000000D-02	6.397130571D+00	-2.593065790D-01	4.012177610D+02
1.000000000D-02	6.396880068D+00	-2.590560767D-01	8.554447923D+02
9.000000000D-03	6.396855018D+00	-2.590310264D-01	9.565938878D+02
8.000000000D-03	6.396829968D+00	-2.590059761D-01	1.083074267D+03
7.000000000D-03	6.396804917D+00	-2.589809258D-01	1.245742517D+03
6.000000000D-03	6.396779867D+00	-2.589558755D-01	1.462692950D+03
5.000000000D-03	6.396754817D+00	-2.589308252D-01	1.766495336D+03
4.000000000D-03	6.396729766D+00	-2.589057749D-01	2.222289211D+03
3.000000000D-03	6.396704716D+00	-2.588807246D-01	2.982066840D+03
2.000000000D-03	6.396679666D+00	-2.588556743D-01	4.501805016D+03
1.000000000D-03	6.396654616D+00	-2.588306240D-01	9.061387723D+03
9.000000000D-04	6.396652111D+00	-2.588281189D-01	1.007465093D+04
8.000000000D-04	6.396649605D+00	-2.588256139D-01	1.134123456D+04

7.000000000D-04	6.396647100D+00	-2.588231089D-01	1.296970454D+04
6.000000000D-04	6.396644595D+00	-2.588206038D-01	1.514100403D+04
5.000000000D-04	6.396642090D+00	-2.588180988D-01	1.818083075D+04
4.000000000D-04	6.396639585D+00	-2.588155938D-01	2.274058011D+04
3.000000000D-04	6.396637080D+00	-2.588130887D-01	3.034017479D+04
2.000000000D-04	6.396634575D+00	-2.588105837D-01	4.553938276D+04
1.000000000D-04	6.396632070D+00	-2.588080787D-01	9.113704390D+04
9.000000000D-05	6.396631820D+00	-2.588078282D-01	1.012698598D+05
8.000000000D-05	6.396631569D+00	-2.588075777D-01	1.139358801D+05
7.000000000D-05	6.396631319D+00	-2.588073272D-01	1.302207638D+05
6.000000000D-05	6.396631068D+00	-2.588070767D-01	1.519339428D+05
5.000000000D-05	6.396630818D+00	-2.588068262D-01	1.823323941D+05
4.000000000D-05	6.396630567D+00	-2.588065756D-01	2.279300721D+05
3.000000000D-05	6.396630317D+00	-2.588063251D-01	3.039262031D+05
2.000000000D-05	6.396630066D+00	-2.588060746D-01	4.559184672D+05
1.000000000D-05	6.396629816D+00	-2.588058241D-01	9.118952631D+05
9.000000000D-06	6.396629791D+00	-2.588057991D-01	1.013223440D+06
8.000000000D-06	6.396629766D+00	-2.588057740D-01	1.139883662D+06
7.000000000D-06	6.396629741D+00	-2.588057490D-01	1.302732518D+06
6.000000000D-06	6.396629715D+00	-2.588057239D-01	1.519864326D+06
5.000000000D-06	6.396629690D+00	-2.588056989D-01	1.823848858D+06
4.000000000D-06	6.396629665D+00	-2.588056738D-01	2.279825655D+06
3.000000000D-06	6.396629640D+00	-2.588056488D-01	3.039786985D+06
2.000000000D-06	6.396629615D+00	-2.588056237D-01	4.559709644D+06
1.000000000D-06	6.396629590D+00	-2.588055987D-01	9.119477621D+06
9.000000000D-07	6.396629588D+00	-2.588055962D-01	1.013275939D+07
8.000000000D-07	6.396629585D+00	-2.588055937D-01	1.139936161D+07
7.000000000D-07	6.396629583D+00	-2.588055912D-01	1.302785017D+07
6.000000000D-07	6.396629580D+00	-2.588055887D-01	1.519916826D+07
5.000000000D-07	6.396629578D+00	-2.588055862D-01	1.823901358D+07
4.000000000D-07	6.396629575D+00	-2.588055837D-01	2.279878155D+07
3.000000000D-07	6.396629573D+00	-2.588055812D-01	3.039839485D+07
2.000000000D-07	6.396629570D+00	-2.588055786D-01	4.559762144D+07
1.000000000D-07	6.396629568D+00	-2.588055761D-01	9.119530122D+07
9.000000000D-08	6.396629567D+00	-2.588055759D-01	1.013281189D+08
8.000000000D-08	6.396629567D+00	-2.588055756D-01	1.139941411D+08
7.000000000D-08	6.396629567D+00	-2.588055754D-01	1.302790267D+08
6.000000000D-08	6.396629567D+00	-2.588055751D-01	1.519922076D+08
5.000000000D-08	6.396629566D+00	-2.588055749D-01	1.823906608D+08
4.000000000D-08	6.396629566D+00	-2.588055746D-01	2.279883406D+08
3.000000000D-08	6.396629566D+00	-2.588055744D-01	3.039844735D+08
2.000000000D-08	6.396629566D+00	-2.588055741D-01	4.559767394D+08
1.000000000D-08	6.396629565D+00	-2.588055739D-01	9.119535372D+08

MLEW ERROR -- BETA LESS THAN 0.00000001

```
DATA INPUT PHASE.

TOTAL NUMBER OF FAILURES =    36

TOTAL NUMBER OF SYSTEMS  =     3

SYSTEM STARTING AND ENDING TIMES.
                                     FAILURES.
  0.          1.972D+02
                             4.300D+00 4.400D+00 1.020D+01 2.350D+01 2.380D+01
                             2.640D+01 7.400D+01 7.710D+01 9.210D+01 1.972D+02
  0.          1.908D+02
                             1.000D-01 5.600D+00 1.860D+01 1.950D+01 2.420D+01
                             2.670D+01 4.510D+01 4.580D+01 7.570D+01 7.970D+01
                             9.860D+01 1.201D+02 1.618D+02 1.806D+02 1.908D+02
  0.          1.958D+02
                             8.400D+00 3.250D+01 4.470D+01 4.840D+01 5.060D+01
                             7.360D+01 9.870D+01 1.122D+02 1.298D+02 1.360D+02
                             1.958D+02
```

ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY FUNCTION.

CONSTANT NOT INVOLVING BETA: A = 3.6731896D+00

ESTIMATED BETA	FUNCTION D(B')	A - D(B')	ESTIMATED LAMBDA
1.000000000D+01	5.172764354D+00	-1.499574705D+00	1.527402235D-22
9.000000000D+00	5.161470246D+00	-1.488280598D+00	2.977461975D-20
8.000000000D+00	5.147396282D+00	-1.474206633D+00	5.803087229D-18
7.000000000D+00	5.129352022D+00	-1.456162373D+00	1.130813934D-15
6.000000000D+00	5.105353381D+00	-1.432163732D+00	2.203137001D-13
5.000000000D+00	5.071828974D+00	-1.398639326D+00	4.291501795D-11
4.000000000D+00	5.021635991D+00	-1.348446342D+00	8.357833094D-09
3.000000000D+00	4.938107813D+00	-1.264918165D+00	1.627398353D-06
2.000000000D+00	4.771244493D+00	-1.098054844D+00	3.168174072D-04
1.000000000D+00	4.271046084D+00	-5.978564354D-01	6.166495375D-02
9.000000000D-01	4.159915038D+00	-4.867253891D-01	1.044615824D-01
8.000000000D-01	4.021006197D+00	-3.478165480D-01	1.769595169D-01
7.000000000D-01	3.842414799D+00	-1.692251504D-01	2.997715275D-01
6.000000000D-01	3.604299575D+00	6.889073354D-02	5.078155206D-01
6.900000000D-01	3.821708868D+00	-1.485192188D-01	3.159962865D-01
6.800000000D-01	3.800393997D+00	-1.272043479D-01	3.330991836D-01
6.700000000D-01	3.778442920D+00	-1.052532716D-01	3.511277462D-01
6.600000000D-01	3.755826720D+00	-8.263707150D-02	3.701320741D-01
6.500000000D-01	3.732514698D+00	-5.932504969D-02	3.901649784D-01
6.400000000D-01	3.708474238D+00	-3.528458948D-02	4.112821287D-01
6.300000000D-01	3.683670652D+00	-1.048100334D-02	4.335422075D-01
6.200000000D-01	3.658067015D+00	1.512263417D-02	4.570070733D-01
6.290000000D-01	3.681146920D+00	-7.957271513D-03	4.358334296D-01
6.280000000D-01	3.678615152D+00	-5.425502957D-03	4.381367604D-01
6.270000000D-01	3.676075308D+00	-2.885659220D-03	4.404522640D-01
6.260000000D-01	3.673527350D+00	-3.377016037D-04	4.427800047D-01
6.250000000D-01	3.670971240D+00	2.218408839D-03	4.451200472D-01
6.259000000D-01	3.673272107D+00	-8.245808135D-05	4.430134543D-01
6.258000000D-01	3.673016782D+00	1.728670081D-04	4.432470270D-01
6.258900000D-01	3.673246578D+00	-5.692924357D-05	4.430368061D-01
6.258800000D-01	3.673221048D+00	-3.139959008D-05	4.430601590D-01
6.258700000D-01	3.673195518D+00	-5.869120840D-06	4.430835132D-01

```
THE FINAL ESTIMATE OF BETA =   6.2587000D-01

THE FINAL ESTIMATE OF LAMBDA =   4.4308351D-01

CONVERGENCE TO   5.8691208D-06
WHICH IS LESS THAN EPSILON =   1.0000000D-05

THE FINAL STEP SIZE IS   1.0000000D-05
```

CRAMER - VON MISES GOODNESS OF FIT TEST.

ESTIMATED BETA = 6.2587000D-01

NUMBER OF FAILURES = 36

UNBIASED ESTIMATE OF BETA = 5.5632889D-01

CRAMER - VON MISES STATISTIC = 1.2263065D-01

REJECT THE WEIBULL INTENSITY MODEL IF THE STATISTIC
EXCEEDS THE APPROPRIATE CRITICAL VALUE FOR M = 33

```
DATA INPUT PHASE.

TOTAL NUMBER OF FAILURES =    12

TOTAL NUMBER OF SYSTEMS  =     1

SYSTEM STARTING AND ENDING TIMES.
                                   FAILURES.

  0.         8.0000D+02
                               4.5000D+01 4.5600D+02 4.6700D+02 4.7700D+02 4.8400D+02
                               4.9200D+02 1.2000D-01 5.6400D+02 6.5000D+01 7.8000D+01
                               8.9000D+01 9.9100D+01
```

ESTIMATION OF THE PARAMETERS OF THE WEIBULL INTENSITY FUNCTION.

CONSTANT NOT INVOLVING BETA: A = 4.70451810D+00

ESTIMATED BETA	FUNCTION D(B')	A - D(B')	ESTIMATED LAMBDA
1.000000000D+01	6.584611728D+00	-1.880093620D+00	1.117587090D-28
9.000000000D+00	6.573500617D+00	-1.868982509D+00	8.940696716D-26
8.000000000D+00	6.559611728D+00	-1.855093620D+00	7.152557373D-23
7.000000000D+00	6.541754585D+00	-1.837236477D+00	5.722045898D-20
6.000000000D+00	6.517945061D+00	-1.813426953D+00	4.577636719D-17
5.000000000D+00	6.484611728D+00	-1.780093620D+00	3.662109375D-14
4.000000000D+00	6.434611728D+00	-1.730093620D+00	2.929687500D-11
3.000000000D+00	6.351278394D+00	-1.646760287D+00	2.343750000D-08
2.000000000D+00	6.184611728D+00	-1.480093620D+00	1.875000000D-05
1.000000000D+00	5.684611728D+00	-9.800936198D-01	1.500000000D-02
9.000000000D-01	5.573500617D+00	-8.689825087D-01	2.926848599D-02
8.000000000D-01	5.434611728D+00	-7.300936198D-01	5.710961816D-02
7.000000000D-01	5.256040299D+00	-5.515221913D-01	1.114341373D-01
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5.050000000D-01	4.704413708D+00	1.043999676D-04	4.103182205D-01
5.059000000D-01	4.707936495D+00	-3.418387575D-03	4.078570950D-01
5.058000000D-01	4.707545694D+00	-3.027585829D-03	4.081298228D-01
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5.054000000D-01	4.705980940D+00	-1.462832339D-03	4.092225588D-01
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5.052000000D-01	4.705197634D+00	-6.795264061D-04	4.097700235D-01
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5.0500000000D-01	4.7044137080D+00	1.0439996760D-04	4.1031822050D-01
5.0509000000D-01	4.7047665520D+00	-2.4844372720D-04	4.1007144120D-01
5.0508000000D-01	4.7047273530D+00	-2.0924508190D-04	4.1009885380D-01
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5.0506000000D-01	4.7046489510D+00	-1.3084313460D-04	4.1015368450D-01
5.0505000000D-01	4.7046097480D+00	-9.1639832430D-05	4.1018110260D-01
5.0504000000D-01	4.7045705430D+00	-5.2434977770D-05	4.1020852250D-01
5.0503000000D-01	4.7045313360D+00	-1.3228570530D-05	4.1023594420D-01
5.0502000000D-01	4.7044921280D+00	2.5979389380D-05	4.1026336780D-01
5.0502900000D-01	4.7045274160D+00	-9.3078444090D-06	4.1023868650D-01

THE FINAL ESTIMATE OF BETA = 5.0502900D-01

THE FINAL ESTIMATE OF LAMBDA = 4.1023869D-01

CONVERGENCE TO 9.3078444D-06
WHICH IS LESS THAN EPSILON = 1.0000000D-05

THE FINAL STEP SIZE IS 1.0000000D-06

```
CRAMER - VON MISES GOODNESS OF FIT TEST.


ESTIMATED BETA =    5.05029000D-01

NUMBER OF FAILURES =      12

UNBIASED ESTIMATE OF BETA =    4.62943250D-01



CRAMER - VON MISES STATISTIC =    1.46452110D-01

REJECT THE WEIBULL INTENSITY MODEL IF THE STATISTIC
EXCEEDS THE APPROPRIATE CRITICAL VALUE FOR M =    12
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DATA INPUT PHASE.

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